Satellite Remote Sensing for Malaria Epidemic Early Warning in a Highland Region of Ethiopia

Michael C. Wimberly[1]

Alemayehu Midekisa[1], Ting-Wu Chuang[1], Geoffrey M. Henebry[1], Yi Liu[2], Gabriel Senay[13]

1 Geographic Information Science Center of Excellence, South Dakota State University

2 Dept. of Electrical Engineering and Computer Science, South Dakota State University

3 USGS Center for Earth Resources Observation and Science (EROS)

Outline

- Exploratory analysis of historical malaria surveillance data (Wimberly et al., 2012, *Tropical Medicine and International Health*)

- Time series analysis of climatic influences on historical malaria cases using remotely-sensed data (Midekisa et al, 2012, *Malaria Journal*)

- Remotely-sensed environmental risk factors for malaria oubreaks (Wimberly et al., 2012, *Proceedings of the International Congress on Environmental Modelling and Software*)

Study Area: Amhara Region of Ethiopia

- Size: 157,000 km² (78% of SD)
- Population: > 18 million (2,234% of SD)
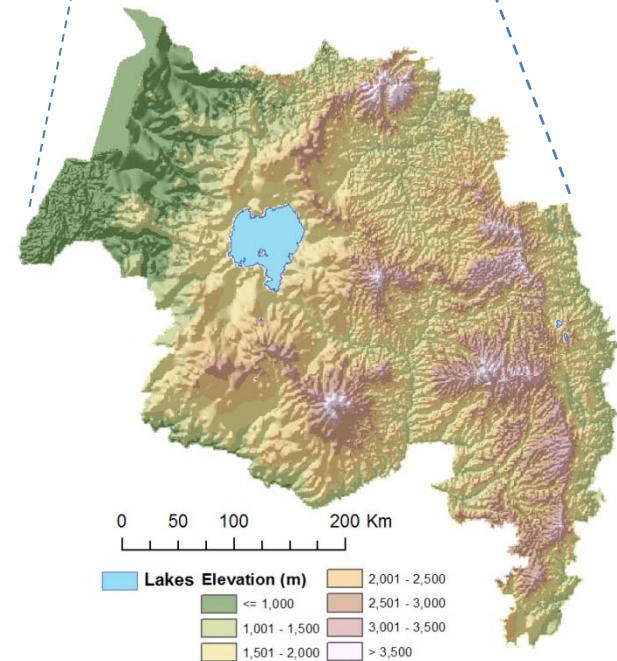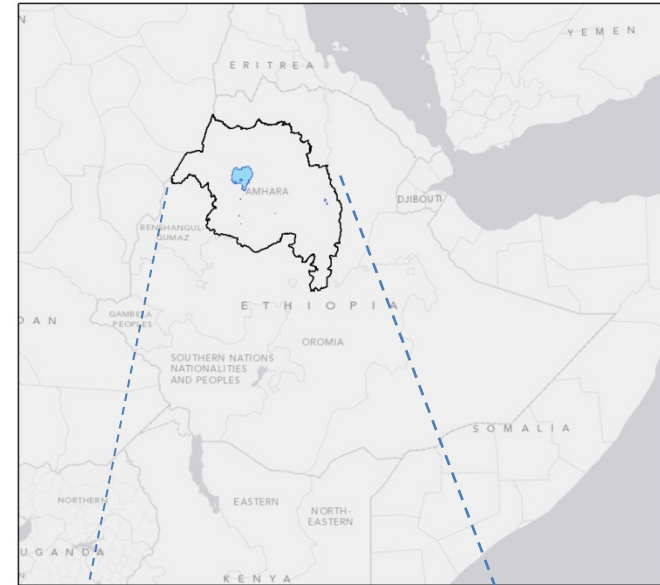
Background – Epidemic Malaria

- Malaria is a leading public health problem in sub-Saharan Africa

- Ethiopia
  - More than 2/3 of the population at risk
  - 9-15 million malaria cases per year

- Epidemic versus endemic malaria
 - 114,000 deaths during the last major epidemic in Ethiopia (2003)

Background – Disease Forecasting

- Public health strategies for disease control and prevention
- Challenge of planning for disease epidemics and other "unpredictable" events
  - Risk of not responding
  - Risk of overresponding
- Importance of accurately forecasting future disease outbreaks
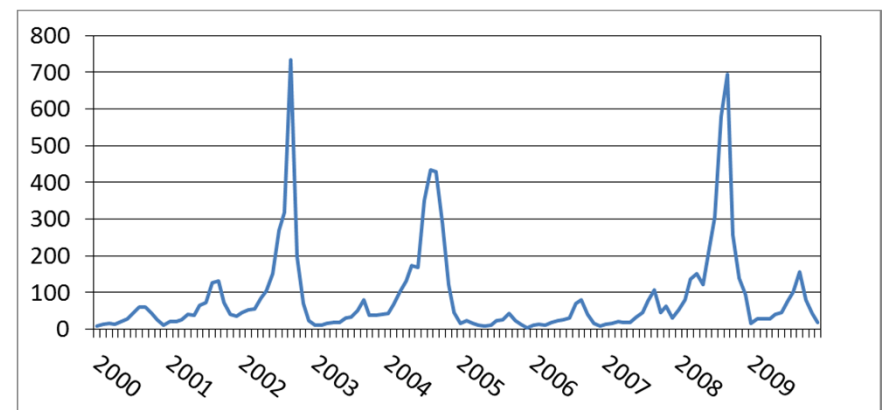
Exploratory Analysis of Malaria Surveillance Data

- Are different malaria surveillance variables (e.g., clinically diagnosed versus confirmed malaria cases) correlated with one another?

- Temporal patterns – how does malaria risk vary over time?

- Spatial patterns – how are malaria cases distributed in space?

- Spatio-temporal patterns (synchrony) – are malaria outbreaks entirely local, or are they synchronized across larger areas?
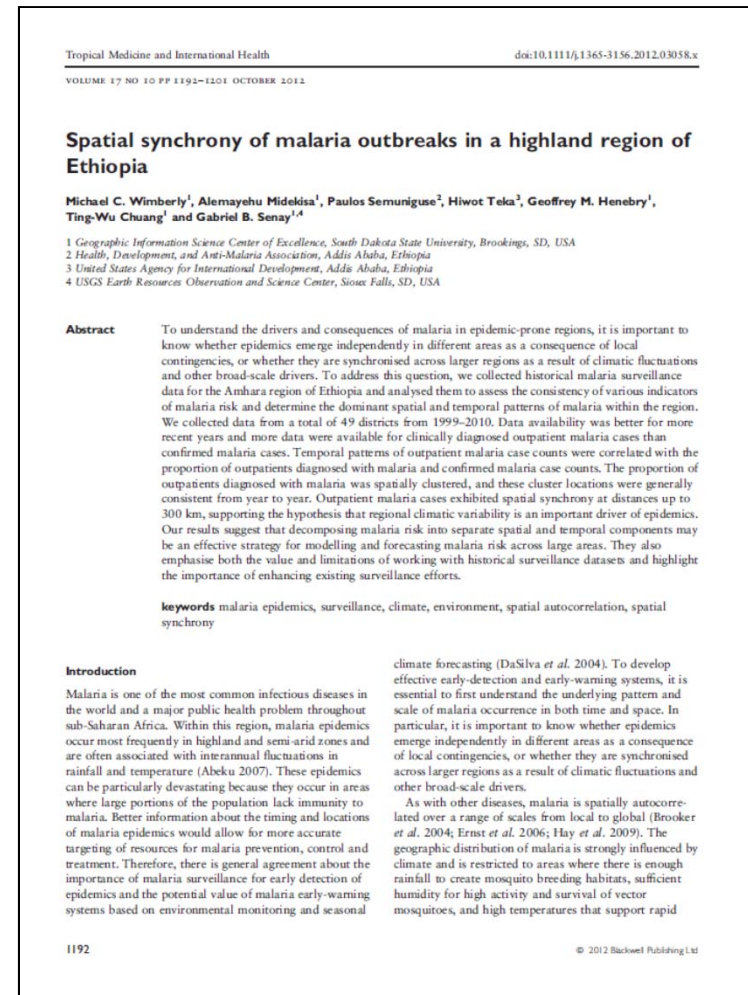
Wimberly et al. (2012) Spatial synchrony of malaria outbreaks in a highland region of Ethiopia. *Tropical Medicine and International Health.* 17: 1192-1201.

Outpatient Malaria Cases
Total number of cases from Sept-Dec
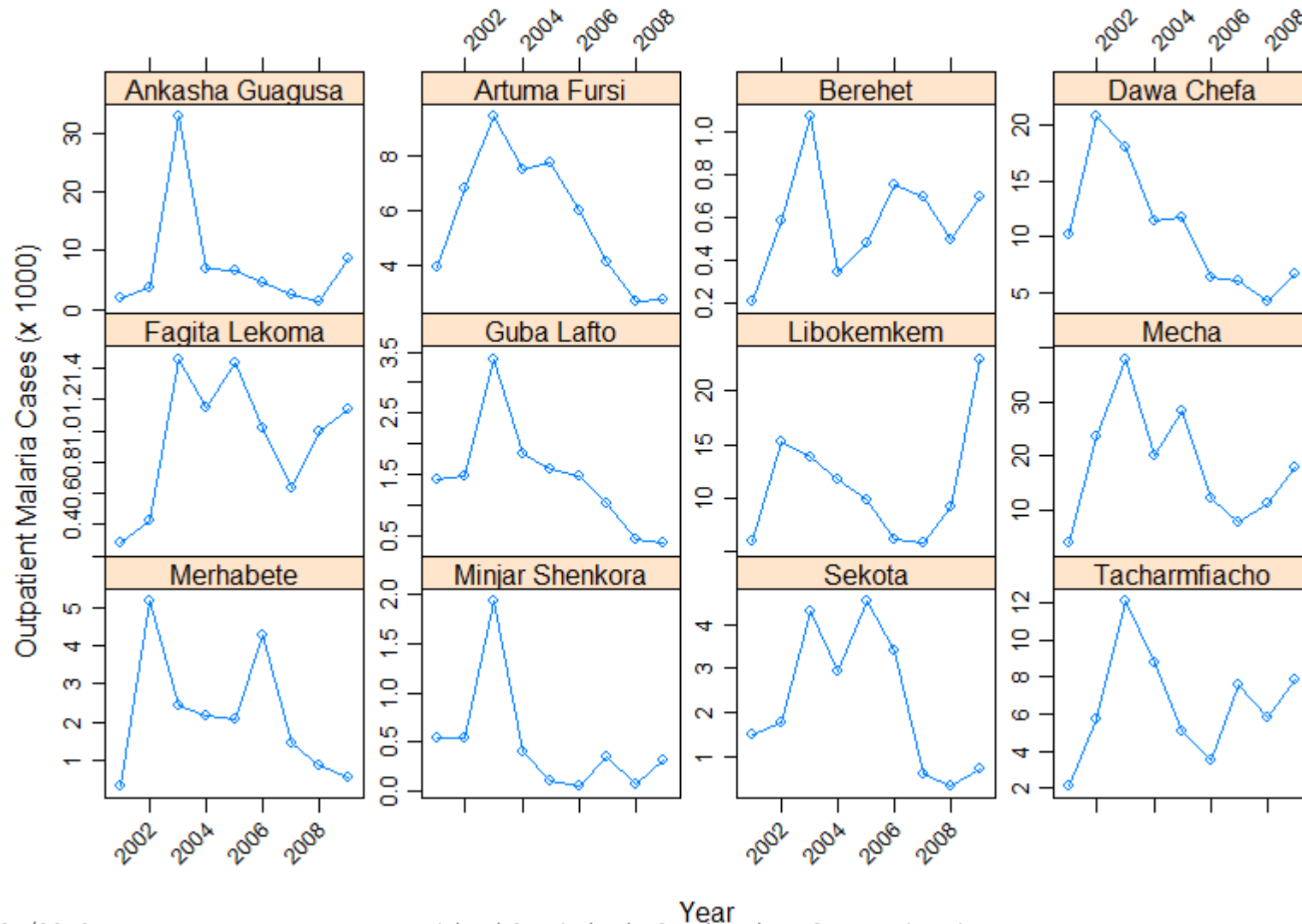
Proportion of outpatients diagnosed with malaria (POM) displayed as a series of *choropleth maps*

Statistical tests confirmed significant spatial clustering (positive spatial autocorrelation) of POM in most years
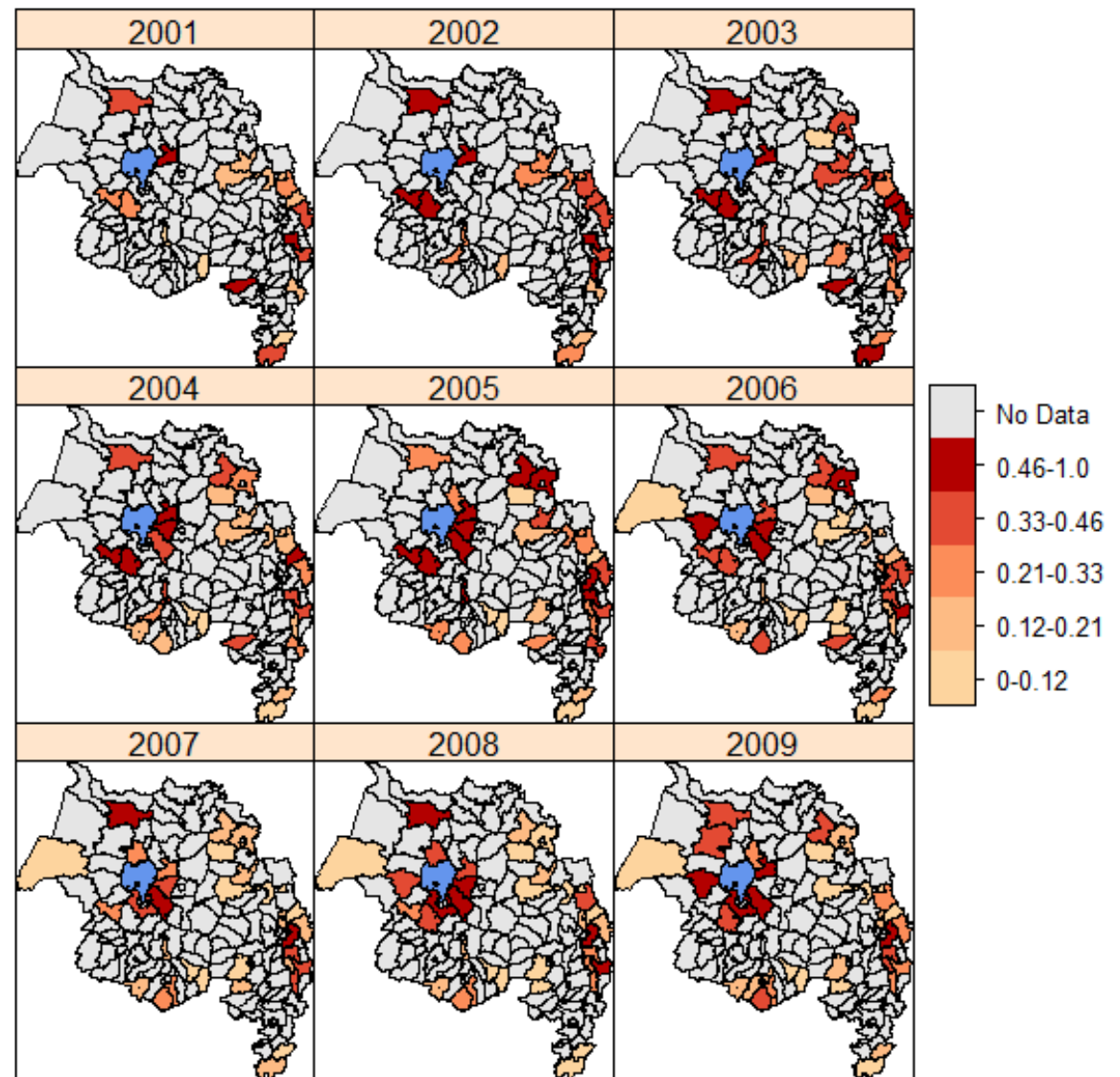
Spatial Synchrony

- Positive spatial synchrony at distances out to 300 km (and possibly longer)

- Confirms spatial structure in the *interannual variability* of malaria incidence

- Provides indirect evidence of a linkages between climatic anomalies and malaria risk
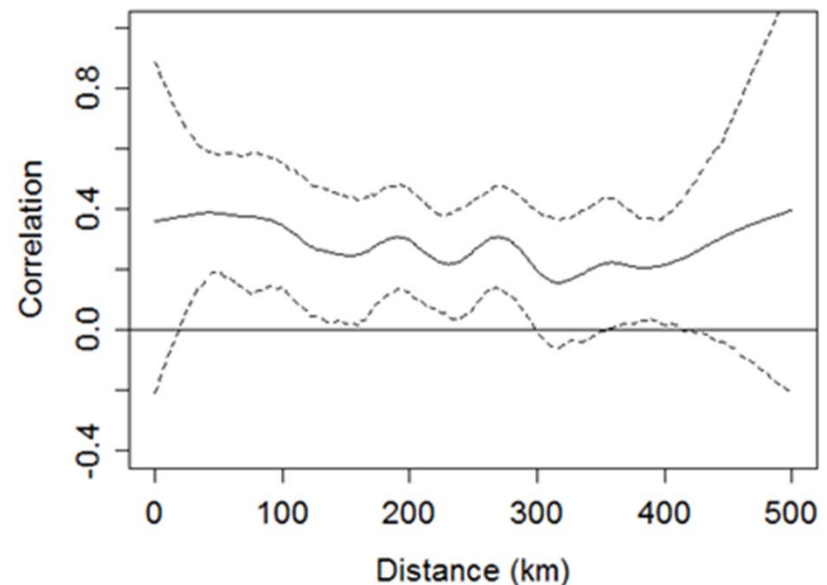
Remotely-sensed metrics of climatic variability

- Are remotely sensed variables significantly associated with temporal patterns of malaria risk?
- What are the temporal lags at which each environmental variable is associated with malaria risk?
- Does the addition of remote sensing covariates improve time series model fits compared to models based only on historical case data?

Midekisa et al. (2012) Remote sensing-based time series models for malaria early warning in the highlands of Ethiopia. *Malaria Journal 11: 165.*

- Woreda-level summaries of climatic variables and surveillance data
- Time Series Analysis
- Monthly Environmental Metrics and Case data
  - Seasonality
  - Interannual Variability
  - Trend

Figure 2
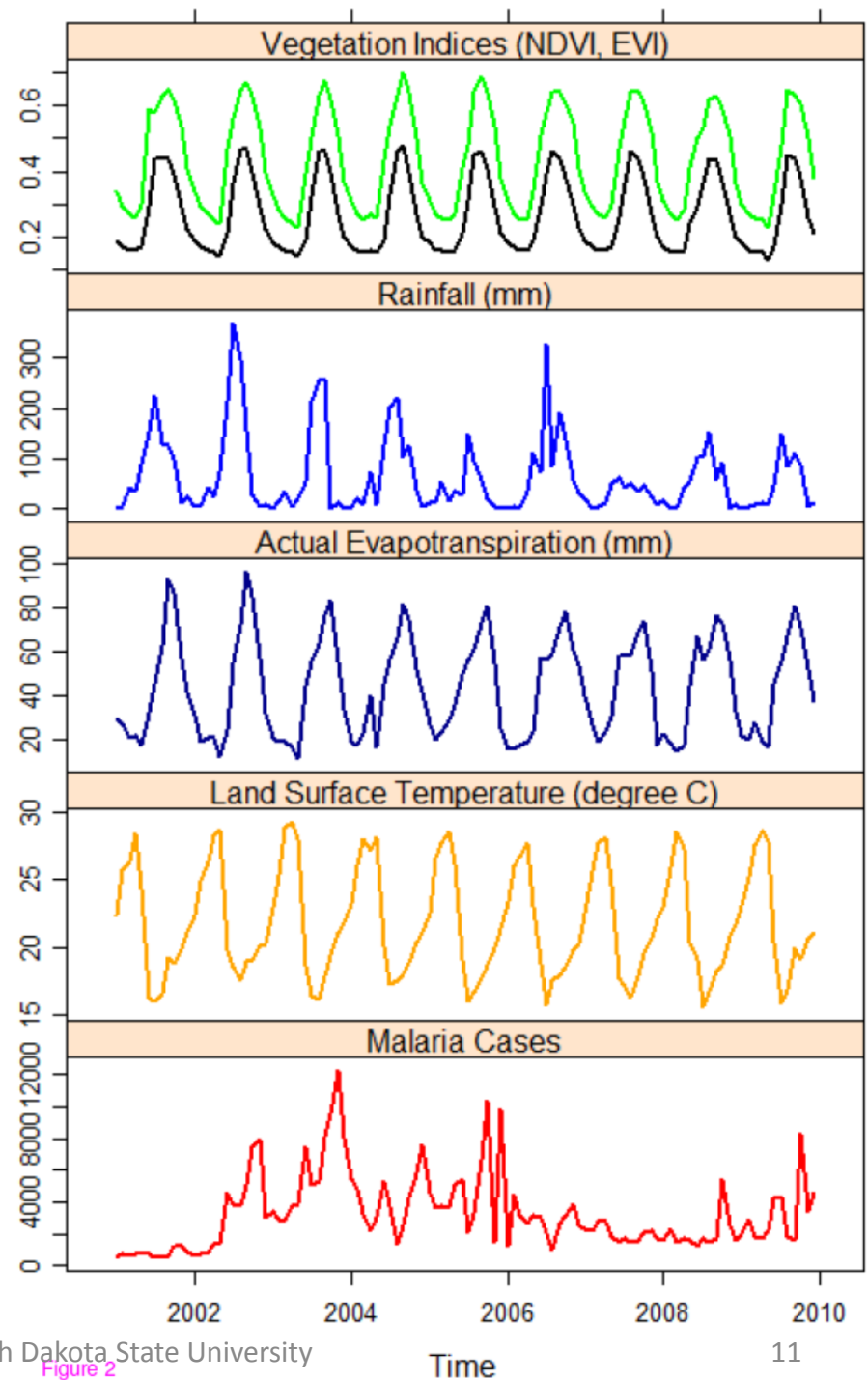
Independent Variables – Land Surface Temperature (LST)

- Temperature of the earth's surface

- Sensitive to both air temperature and land cover

- MODIS Terra

- 8-day temporal resolution, 1 km spatial resolution
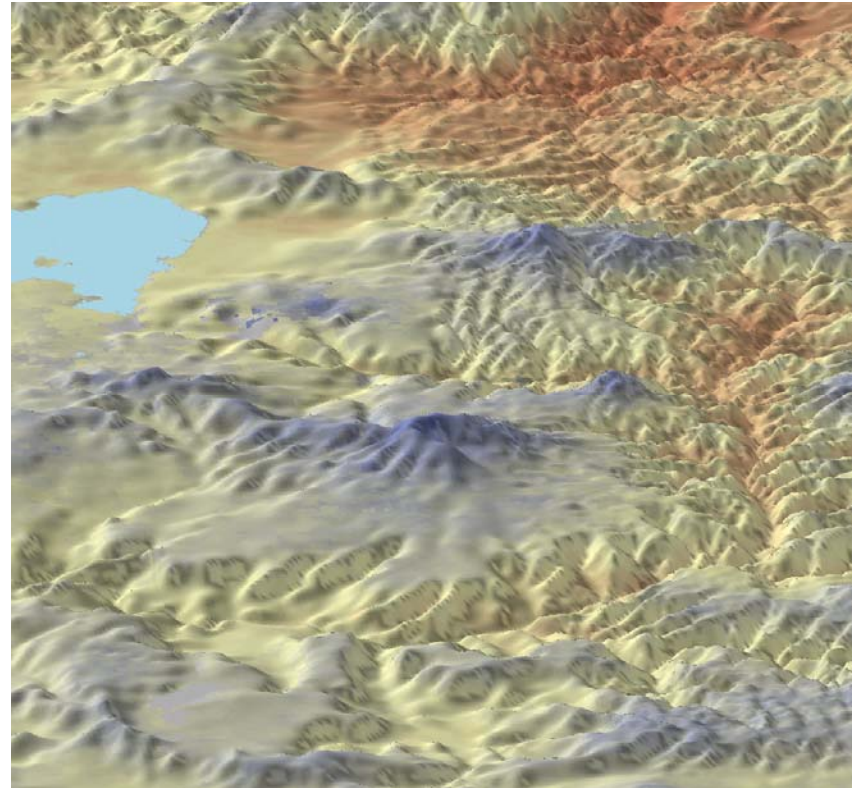
MODIS Terra land surface temperature (red=warm, blue=cool)

Independent Variables – Normalized Difference Vegetation Index (NDVI)

- Indicator of actively photosynthesizing vegetation
- Sensitive to a variety of environmental factors
- MODIS Terra/Aqua BRDF-corrected reflectance
- 8-day temporal resolution, 1 km spatial resolution

Source: EU Global Climate Change Alliance
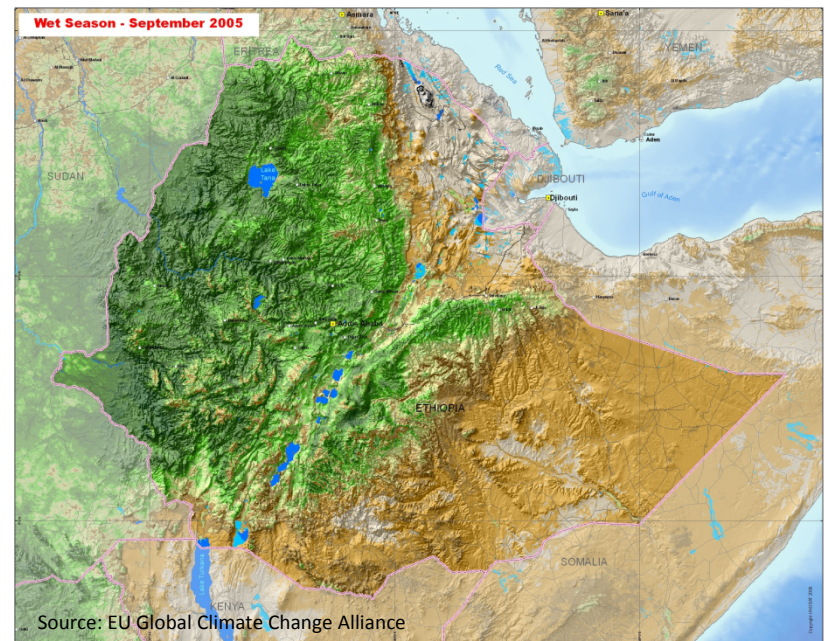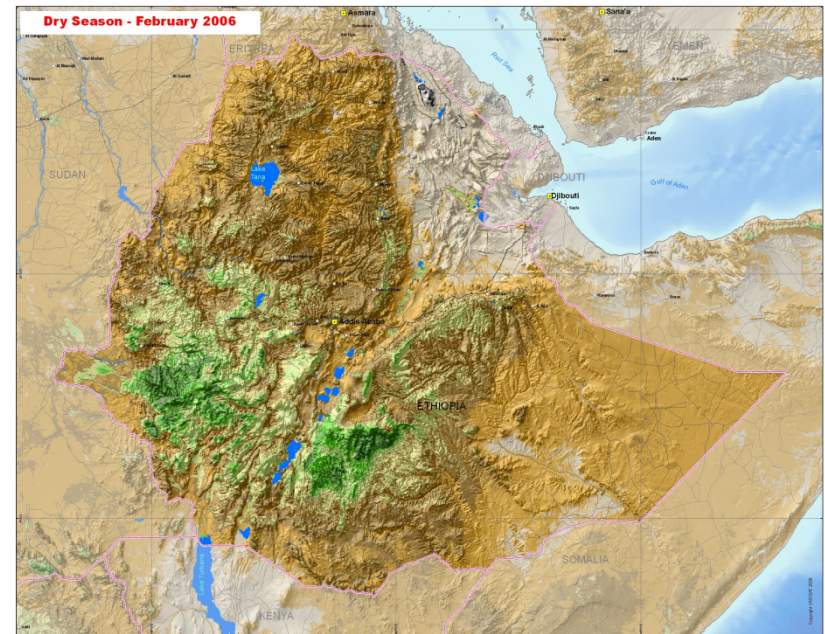
Independent Variables – Rainfall

- Tropical Rainfall Monitoring Mission (TRMM)

- Synthesizes multiple data sources to estimate rainfall

- 1-day (8-day) temporal resolution, 0.25^o spatial resolution

- Data Accessed via Giovanni using TOVAS
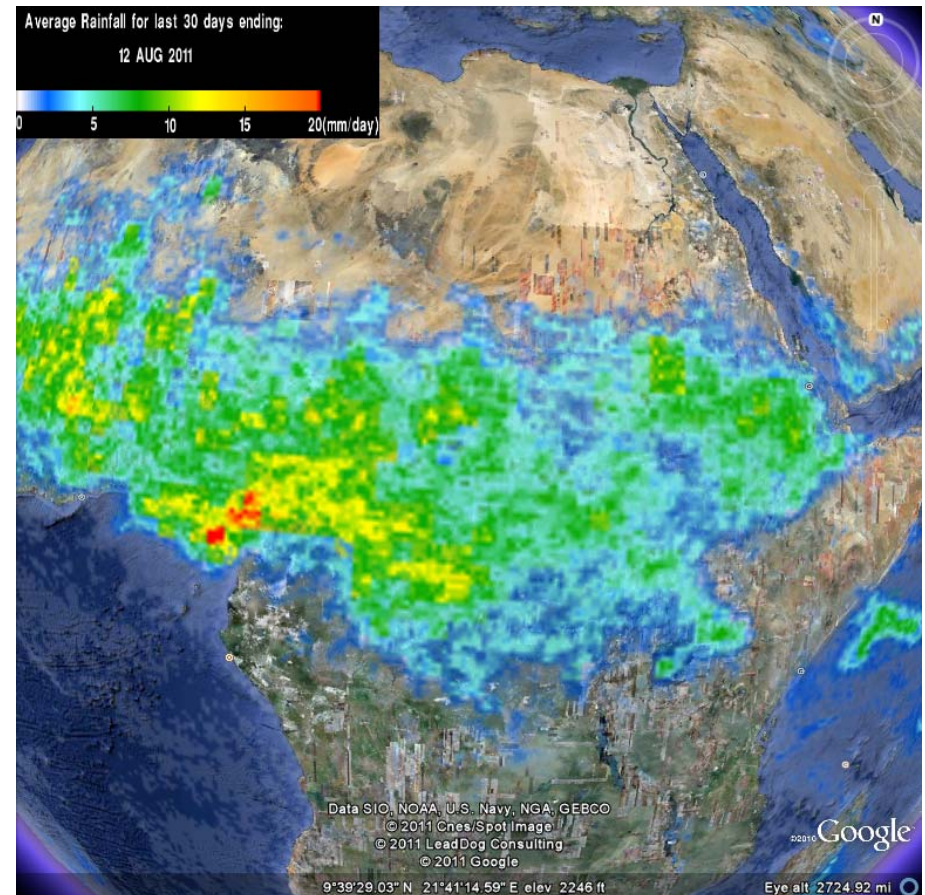
TRMM rainfall average for the last 30 days, August 12, 2011

Independent Variables – Actual Evapotranspiration (ETa)

- Sensitive to soil moisture availability

- Modeled using the simplified surface energy balance method developed by Dr. Gabriel Senay

- 8-day temporal resolution, 1 km spatial resolution
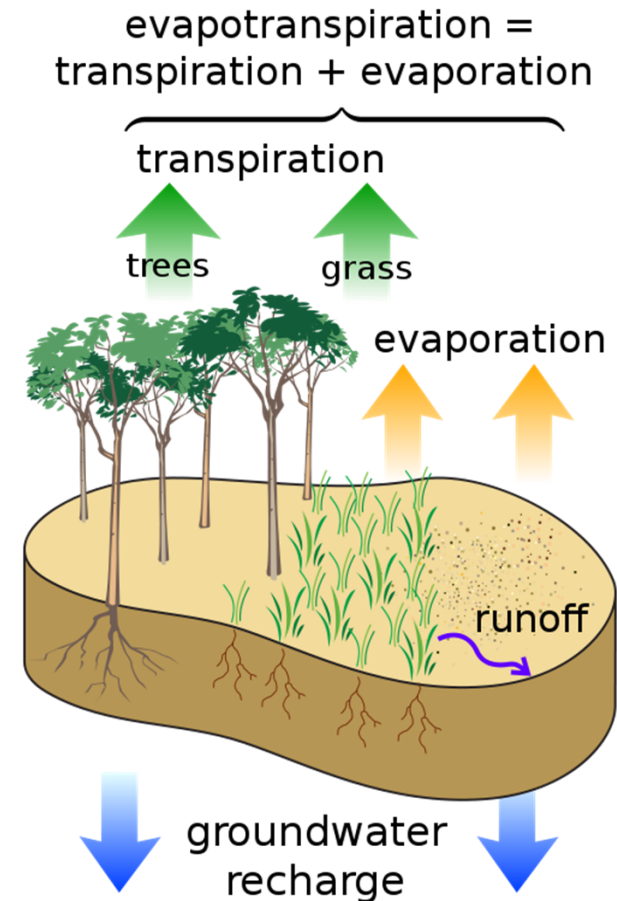
Approaches to Time Series Analysis

- Monthly Differencing
  - Trend removal
- Seasonal Differencing
  - Seasonality removal
- Lagged associations with environment variables
  - How will temperature and precipitation fluctuations during the current time period influence malaria risk during future time periods
- Autoregression
  - Lagged associations with malaria cases in preceding months

Observed, Fitted, and Predicted Malaria Cases for 6 of the 12 Woredas Studied
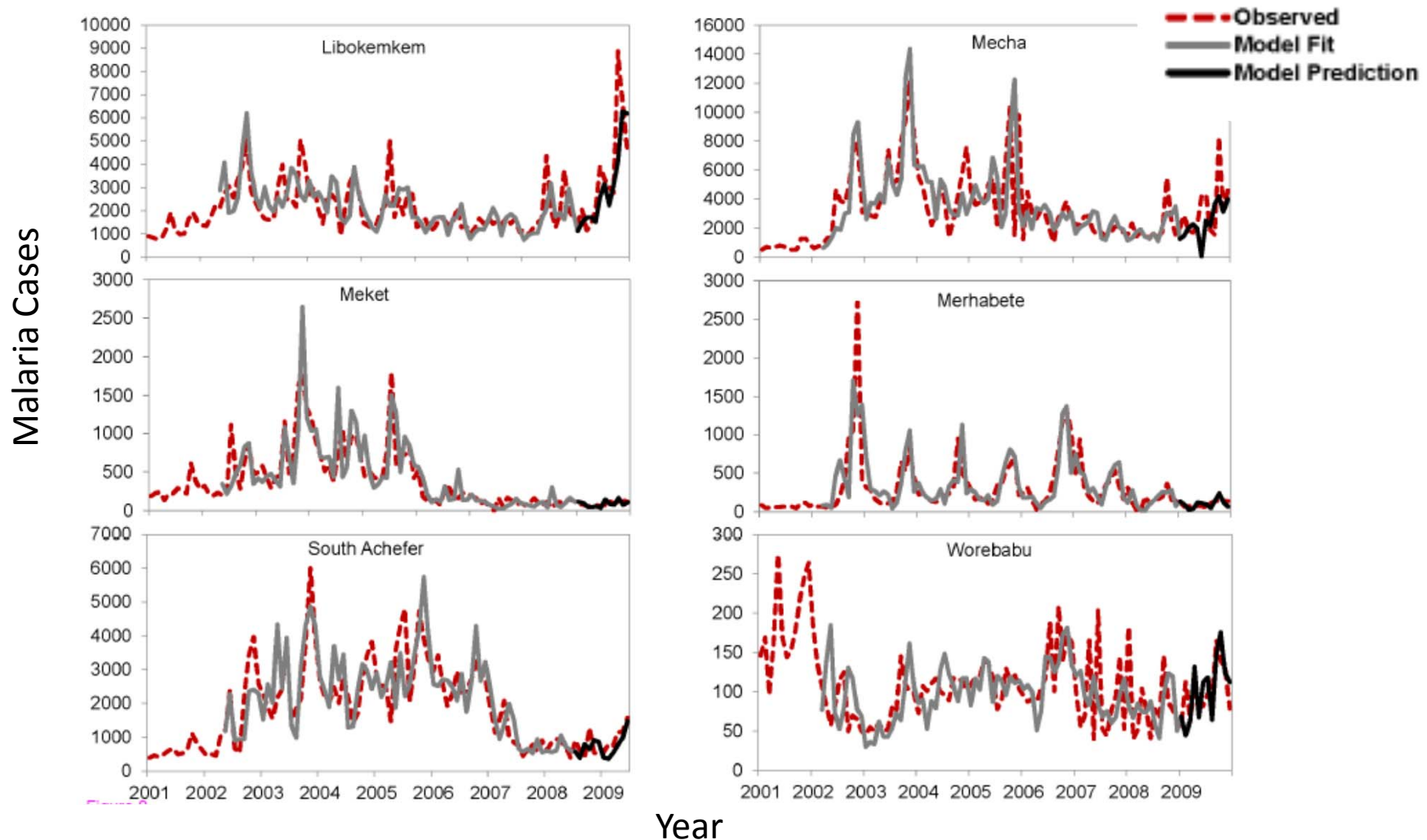
Summary of Results

- Temperature, precipitation, and evapotranspiration anomalies in a given month influence malaria risk in future months
- The influences of the remotely sensed climatic variables were consistent across sites
  - Shorter for temperature (1 month)
  - Longer for precipitation and other moisture variables (2-3 months)
- Models fit was improved by incorporating remotely-sensed environmental variables in to the models
- Models had relatively high forecasting accuracy, but only if lagged case data was used to make the predictions (autoregressive term)

Remotely-Sensed Environmental Risk Factors

- Identify environmental risk factors associated with malaria outbreaks using satellite remote sensing
  - Focus on the main malaria season (Sept-Dec)
  - Predict interannual variability in malaria risk
  - Are remotely sensed environmental anomalies earlier in the calendar year (Jan-Aug) associated with increased malaria risk at the end of the year?

A Computer System for Forecasting Malaria Epidemic Risk Using Remotely-Sensed Environmental Data

Michael C. Wimberly[1], Ting-Wu Chuang[1], Geoffrey M. Henebry[1], Yi Liu[2], Alemayehu Midekisa[1], Paulos Semuniguse[3], Gabriel Senay[4]
[1]South Dakota State University, Geographic Information Science Center of Excellence, Brookings, SD USA
[2]South Dakota State University, Department of Electrical Engineering and Computer Science, Brookings SD USA
[3]Health, Development, and Anti-Malaria Association, Addis Ababa, Ethiopia
[4]United States Geological Survey, Earth Resource Observation and Science (EROS) Center, Sioux Falls, SD USA

Abstract: Epidemic malaria is a major public health problem in the highlands of East Africa. Identifying the climatic triggers that increase malaria risk affords a basis for developing environmentally-driven early warning systems. Satellite remote sensing provides a wide range of environmental metrics that are sensitive to temperature, rainfall, and other climatic variables. The goals of this study were to develop a computer application for automatically acquiring and processing remote sensing data, and to test the utility of these data for modelling and forecasting malaria epidemics in the Amhara region of Ethiopia. The application was programmed using JAVA for user interface development and overall system control. Spatial analyses were carried out using Python scripts to call ArcGIS geoprocessing functions, and PostgreSQL was used to store and manipulate the resulting data summaries. Remotely-sensed variables included land surface temperature from MODIS/Terra, vegetation indices computed using MODIS nadir BRDF-adjusted reflectance, precipitation estimates from the Tropical Rainfall Measuring Mission, and actual evapotranspiration modelled using the simplified surface energy balance method. Historical remote sensing data from 2000-2010 were summarized at the district level by 8-day MODIS composite periods, and transformed to deviations from their 11-year means. Time series of monthly malaria outpatient cases were collected for 19 districts in the Amhara region and used to compute risk indices for the main epidemic season from September-December. Malaria epidemics during this season were associated with a higher-than-normal number of malaria cases in May-June, higher-than normal rainfall in January-May, and warmer-than-normal temperatures in May-June. A cross-validated statistical model containing these variables predicted more than 50% of the variability in malaria relative risk. Continued environmental monitoring using satellite remote sensing will allow us to forecast the environmental risk of malaria epidemics in future years and validate these initial results.

Keywords: Malaria; early warning; remote sensing; geoinformatics.

1   INTRODUCTION

Malaria is a globally important disease that imposes an immense public health burden throughout the developing world, particularly in sub-Saharan Africa. Marginal environments that support unstable transmission, such as highland and semi-arid regions, pose a particular challenge for malaria control and prevention [Abeku, 2007]. Although malaria transmission in these areas is low and often seasonal, interannual fluctuations in rainfall and temperature can increase transmission rates and trigger devastating epidemics. Because of the low immunity
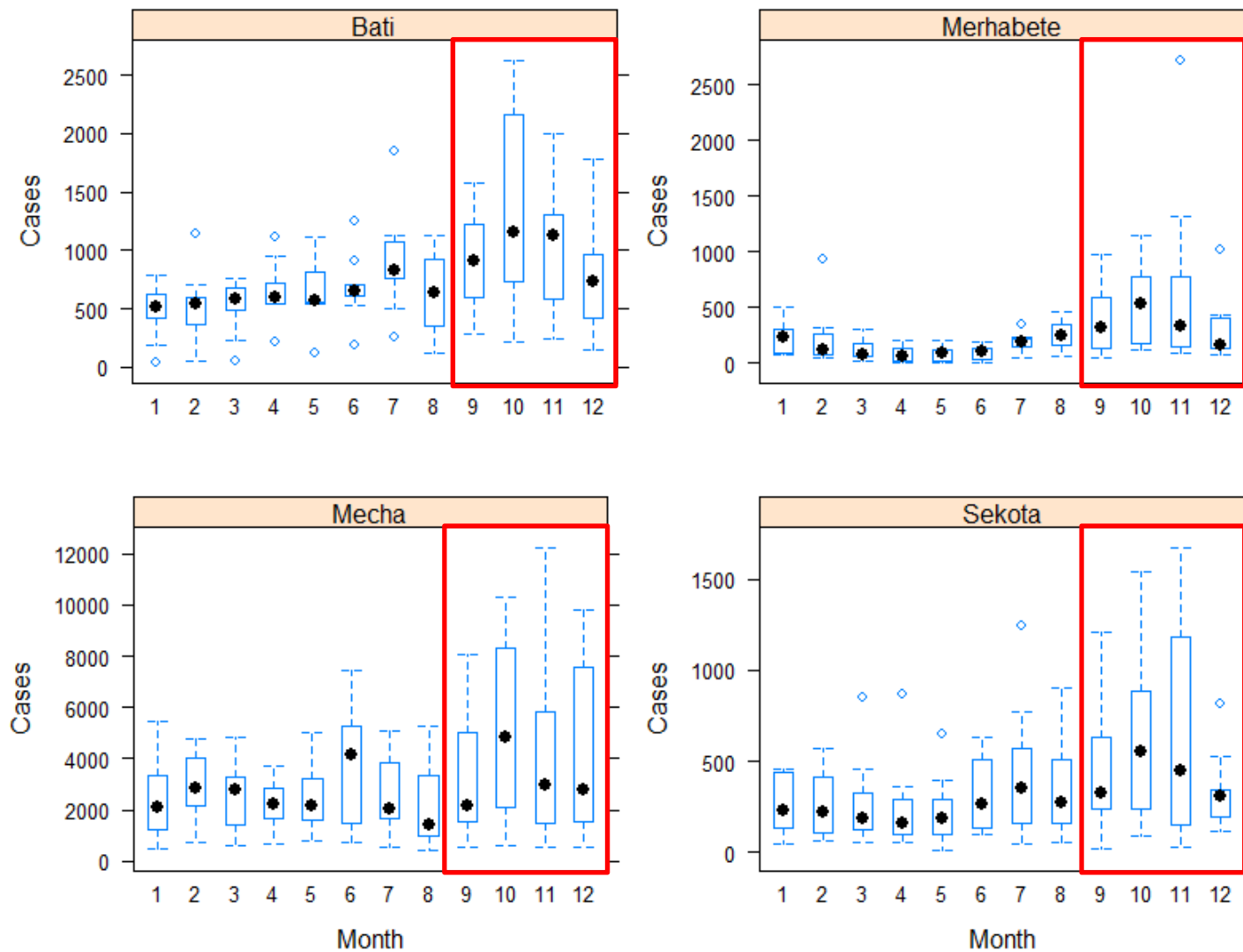
Wimberly et al. (2012). [A computer system for forecasting malaria epidemic risk using remotely-sensed environmental data](#) . Proceedings of the International Congress on Environmental Modelling and Software. Leipzig, Germany, July 1-5.
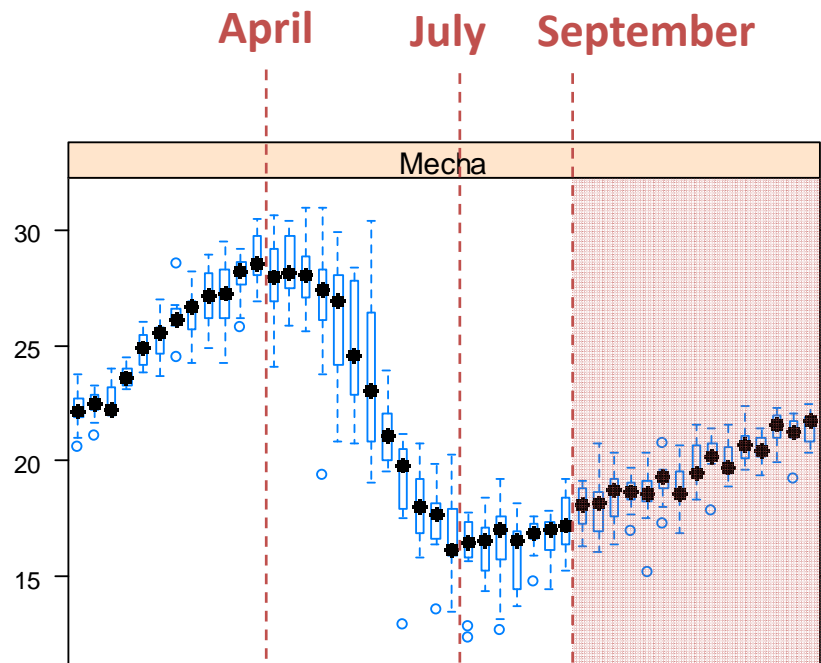
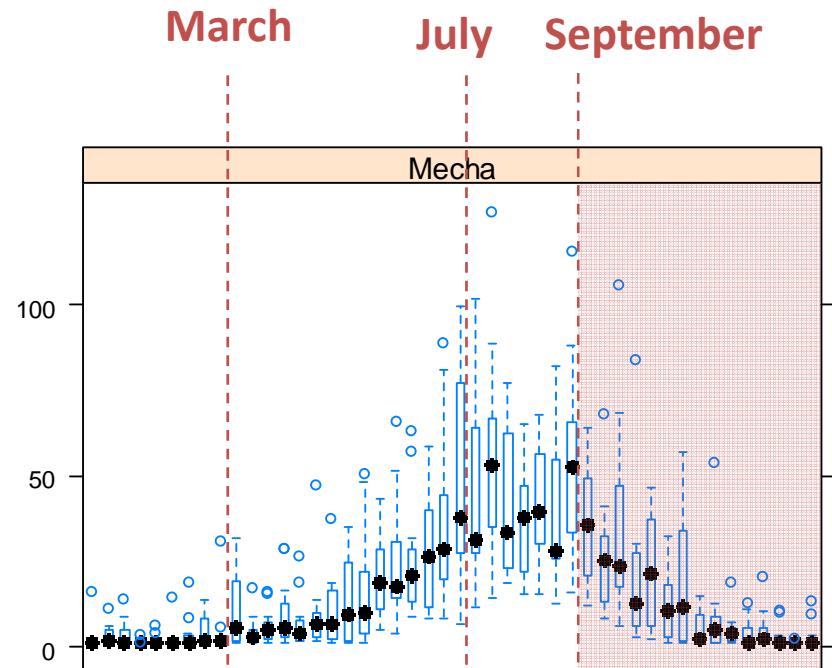# Seasonality of Malaria
Outpatient Cases from Four Woreda

# Seasonality of Climate
Mecha Woreda

MODIS Land Surface Temperature

TRMM Rainfall

Dependent Variable – Relative Risk

- $LRR_{ij} = Observed\ Risk/Expected\ Risk$

- $LRR_{ij} = \ln\left(\dfrac{CASE_{ij}}{POP_i} \Big/ \dfrac{\overline{CASE_i}}{POP_i}\right)$

- $LRR_{ij} = \ln\left(CASE_{ij}/\overline{CASE_i}\right)$

- $LRR_{ij} = \ln\left(CASE_{ij}\right) - \ln\left(\overline{CASE_i}\right)$

  - $CASE$ = Number of outpatient cases from September-December
  - POP = Population at risk
  - i indexes woreda, j indexes years

Environmental Anomalies: Deviation Formula

- $DRSI_{ij} = 100 \times \dfrac{RSI_{ij} - \overline{RSI_i}}{\overline{RSI_i}}$

  - RSI = Remote Sensing Index
  - i indexes woreda, j indexes years


Woreda

Years
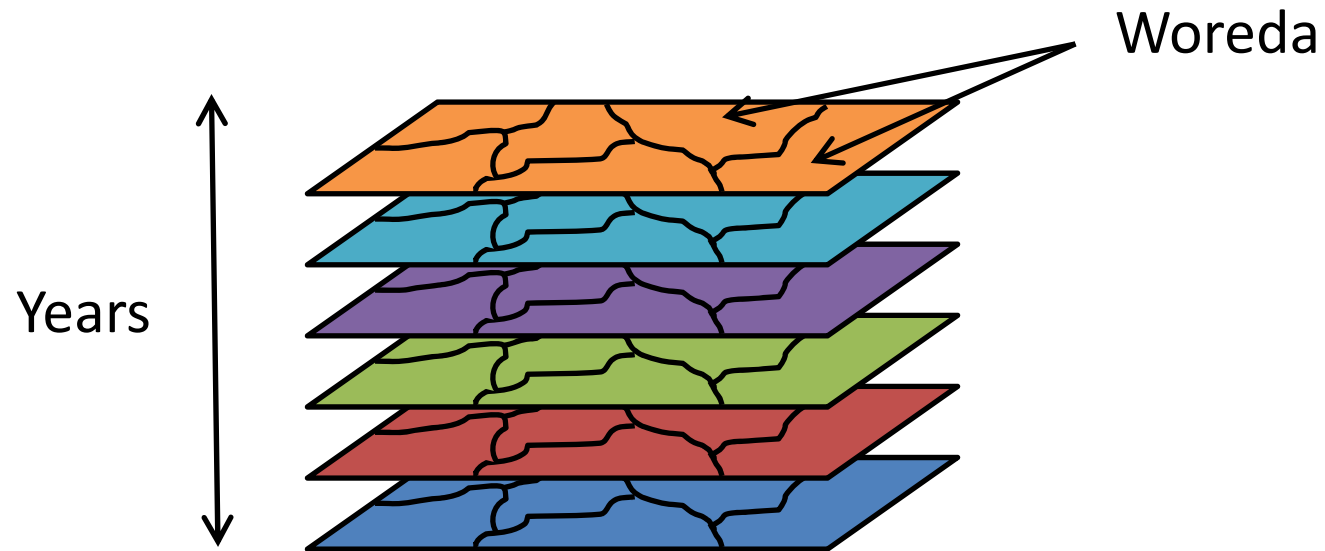
Environmental Anomalies – Correlations with Sept-Dec Malaria Relative Risk
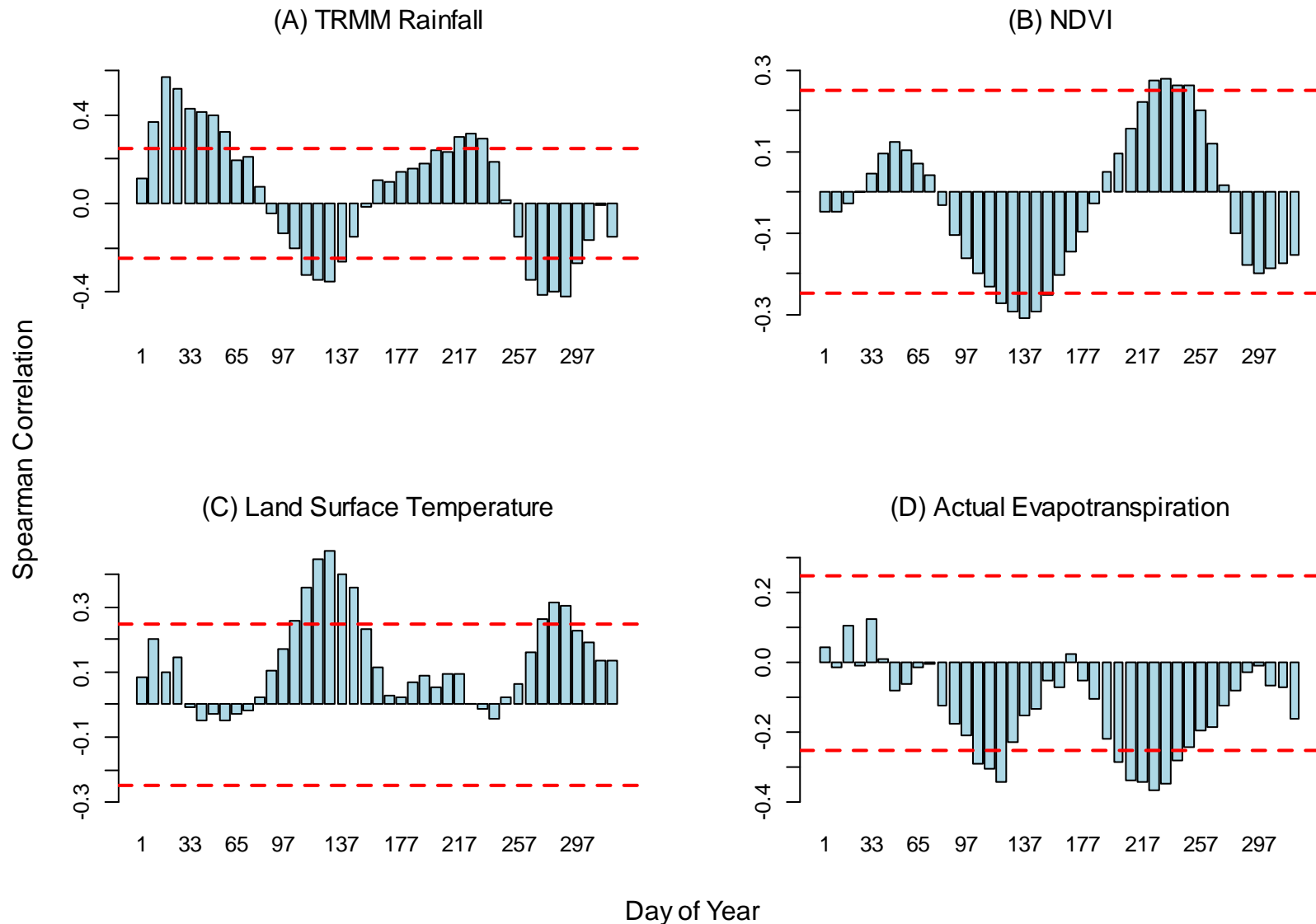
Summary – Environmental Risk Factors

- Prior to the peak malaria season (January-August)
  - Higher than average rainfall in February
  - Lower than average rainfall/higher temperature in June
  - Higher than average rainfall in September
- Meteorological "trigger points" that set the stage for upcoming epidemics

Rainfall

Land Surface Temperature
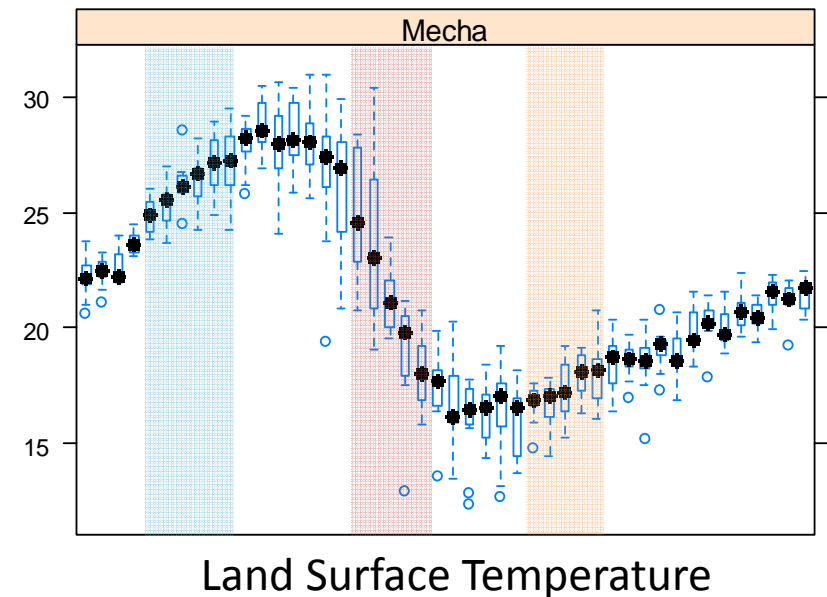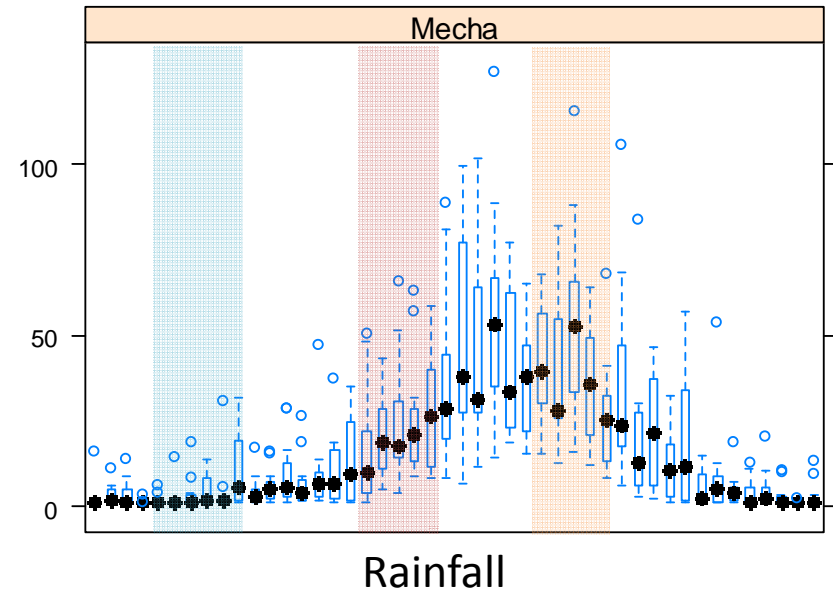
Models of Relative Risk Based on Environmental Anomalies Prior to the Start of the Rainy Season
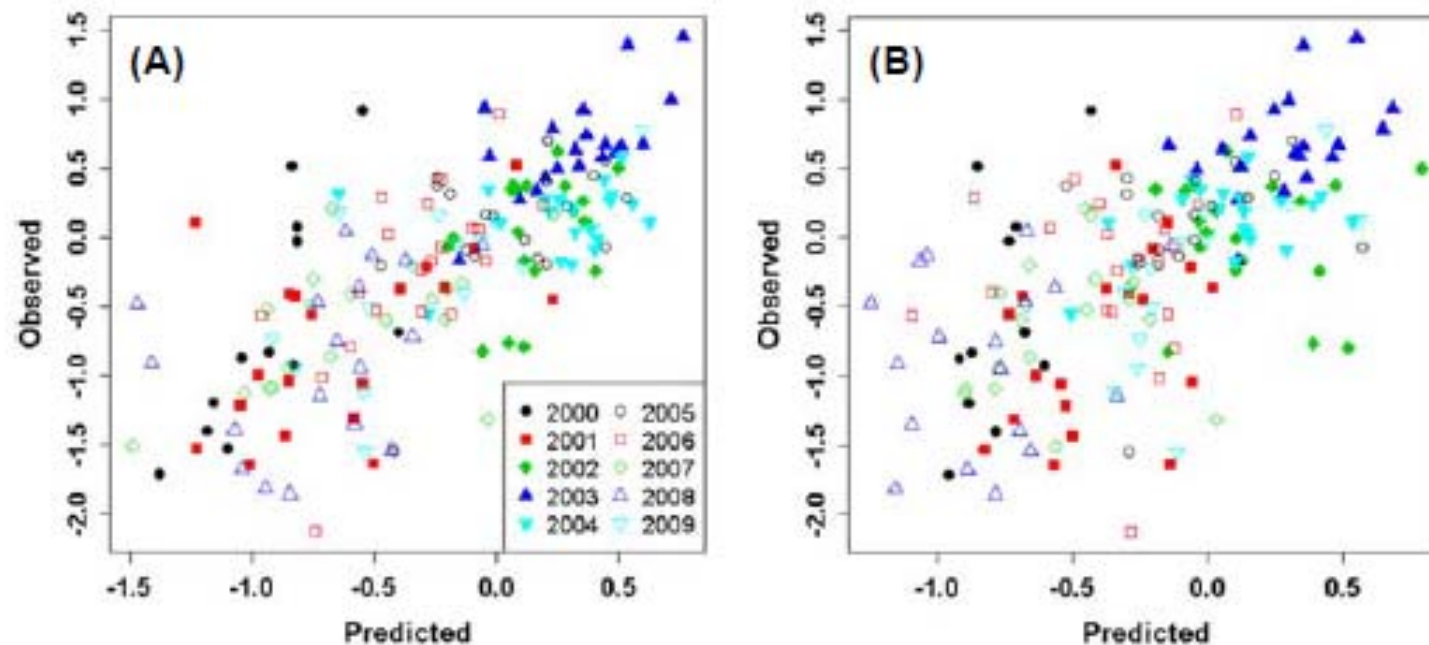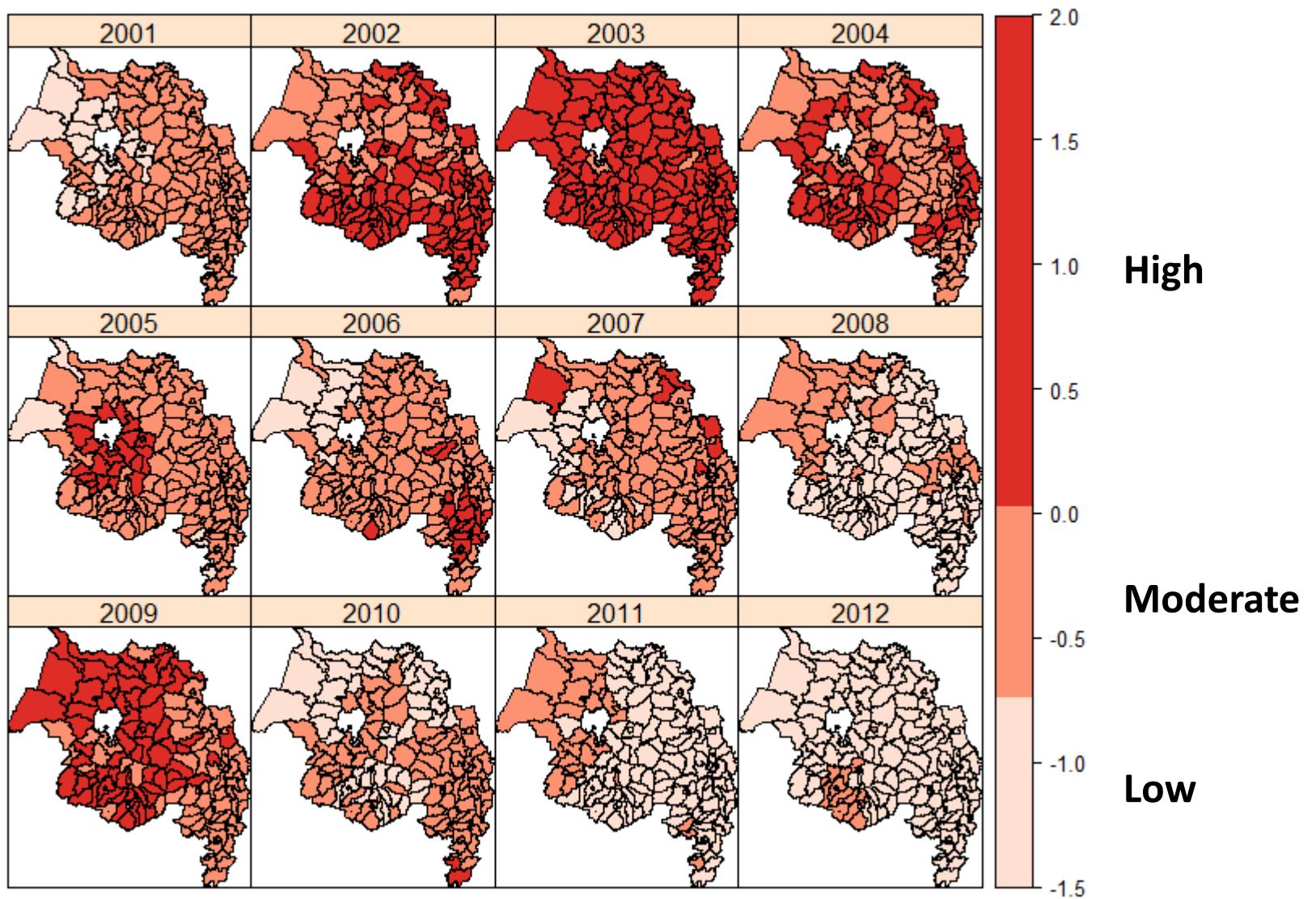

Figure 3: Cross-validation of a model of relative risk of malaria epidemics during September-December (LRR$_p$). (A) Predictions based on remotely sensed environmental variables and malaria relative risk during May-June (LRR$_e$). (B) Predictions based on remotely sensed environmental variables alone.

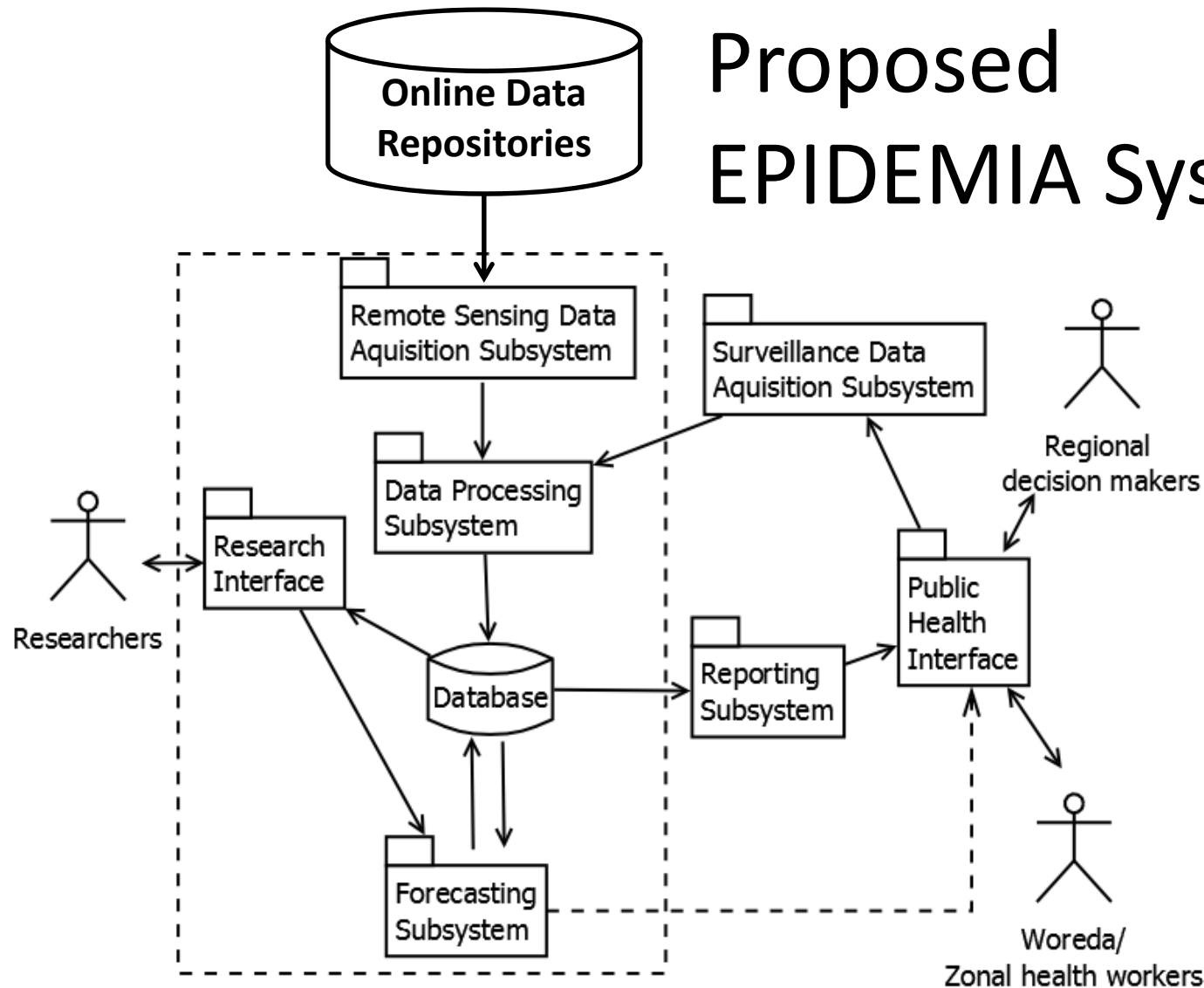# Predicted Relative Risk

Next Steps

- Continue to update and refine models for malaria risk mapping and forecasting

- Develop new remote sensing products for mapping surface water

- Improve automation of remote sensing data processing

- Devise tools and techniques for integrating disease surveillance and environmental monitoring

Proposed EPIDEMIA System

Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA)

Acknowledgements

- South Dakota State University
  - Alemayehu Midekisa, GIScCE
  - Ting-Wu Chuang, GIScCE
  - Geoffrey Henebry, GIScCE
  - Mike Hildreth, Depts. of Biology/Microbiology and Veterinary Science
  - Yi Liu, Dept. of Electrical Engineering and Computer Science
- USGS Center for EROS
  - Gabriel Senay

- Health, Development, and Anti-Malaria Association
  - Abere Mihretie
  - Hiwot Teka
  - Paulos Semunigus
- Federal Democratic Republic of Ethiopia Ministry of Health
- Amhara Regional Health Bureau
- Funding
  - NIH/NIAID
  - NASA

http://globalmonitoring.sdstate.edu/eastweb/